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 Advance Issues of E-Commerce and Web-Based Information Systems, WECWIS, 1999. International Conference on , 8-9 April 1999  
 Pages:2 - 10
- [Abstract] [PDF Full-Text (220 KB)] IEEE CNF
- 
- 3 iJADE Stock Advisor: An Intelligent Agent Based Stock Prediction System Using Hybrid RBF Recurrent Network**  
*Lee, R.S.T.;*  
 Systems, Man and Cybernetics, Part A, IEEE Transactions on , Volume: 34 , Issue: 3 , May 2004  
 Pages:421 - 428
- [Abstract] [PDF Full-Text (520 KB)] IEEE JNL
- 
- 4 A fully electronic stock interchange**  
*Hauser, H.;*  
 Venture Capital, IEE Half Day Colloquium on , 6 Feb 1995  
 Pages:1/1 - 110
- [Abstract] [PDF Full-Text (316 KB)] IEE CNF
- 
- 5 An experimental field trial of a large vocabulary speaker independent recognition system**

*Myoung-Wan Koo; Il-Hyun Sohn; Che-Hong Ahn;*  
Interactive Voice Technology for Telecommunications Applications, 1994., Second  
IEEE Workshop on , 26-27 Sept. 1994  
Pages:33 - 36

[Abstract] [PDF Full-Text (252 KB)] IEEE CNF

---

**6 Collective intelligence: a new approach to stock price forecasting**

*Kaplan, C.A.;*  
Systems, Man, and Cybernetics, 2001 IEEE International Conference on , Volume:  
5 , 7-10 Oct. 2001  
Pages:2893 - 2898 vol.5

[Abstract] [PDF Full-Text (470 KB)] IEEE CNF

---

**7 Stock returns: momentum, volatility and interest rates**

*Yue Fang; Wada, S.; Moody, J.;*  
Computational Intelligence for Financial Engineering, 2003. Proceedings. 2003 IEEE  
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Pages:379 - 385

[Abstract] [PDF Full-Text (948 KB)] IEEE CNF

---

**8 Fuzzy logic based stock trading system**

*Simutis, R.;*  
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the IEEE/IAFE/INFORMS 2000 Conference on , 26-28 March 2000  
Pages:19 - 21

[Abstract] [PDF Full-Text (204 KB)] IEEE CNF

---

**9 Building long/short portfolios using rule induction**

*John, G.H.; Miller, P.;*  
Computational Intelligence for Financial Engineering, 1996., Proceedings of the  
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Pages:134 - 140

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system**

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neural networks**

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Pages:1793 - 1798 vol.3

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[1](#) [2](#) [3](#) [4](#) [5](#) [6](#) [7](#) [8](#) [9](#) [10](#) [11](#) [12](#) [13](#) [14](#) [15](#) [16](#) [17](#) [18](#) [19](#) [20](#) [21](#) [22](#) [23](#) [24](#)

[25](#) [26](#) [27](#) [28](#) [29](#) [30](#) [31](#) [32](#) [33](#) [34](#) [Next](#)



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Pages:726 - 734

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Pages: 364 - 371

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Pages:6/1 - 6/3

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Pages:1170 - 1174 vol.2

[\[Abstract\]](#) [\[PDF Full-Text \(292 KB\)\]](#) [IEE JNL](#)

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**13 Design and implementation of multi-threaded object request broker**  
*Yue-Shan Chang; Lo, W.; Chii-Jet Wang; Shyan-Ming Yuan; Liang, D.;*  
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Pages:740 - 747

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Conference on , 19-25 April 1998  
Pages:43 - 52

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**15 SOAP cleans up interoperability problems on the Web**  
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Pages:52 - 55

[\[Abstract\]](#) [\[PDF Full-Text \(196 KB\)\]](#) [IEEE JNL](#)

---

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*Pages:177 - 182*

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**2 Modeling the treatment scheme of sustained ventricular tachycardia with a Bayesian belief network**

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*Pages:585 - 588*

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**3 Probabilistically predicting penetrating injury for decision support**

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*Pages:44 - 49*

[\[Abstract\]](#) [\[PDF Full-Text \(368 KB\)\]](#) **IEEE CNF**

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*Pages:11 - 20*

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**5 Construction and application of Bayesian networks in flood decision**

**supporting system**

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Machine Learning and Cybernetics, 2002. Proceedings. 2002 International Conference on , Volume: 2 , 4-5 Nov. 2002  
Pages:718 - 722 vol.2

[\[Abstract\]](#) [\[PDF Full-Text \(511 KB\)\]](#) [IEEE CNF](#)

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Systems, Man, and Cybernetics, 1998. 1998 IEEE International Conference on , Volume: 1 , 11-14 Oct 1998  
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[\[Abstract\]](#) [\[PDF Full-Text \(532 KB\)\]](#) [IEEE CNF](#)

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**8 Plausible reasoning theory in reliability-centered maintenance analysis**

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Pages:367 - 371

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**9 Collaborative decision making and intelligent reasoning in judge advisor systems**

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# A recipe for Bayesian network driven fisheries stock assessment

## Ingredients

- One personal computer, with at least 1 GB of random access memory
- Bayesian network software, see <http://www.ai.mit.edu/~murphyk/Bayes/bnsift.html> for different products, and see Jensen (1996) for an introduction
- Fisheries stock assessment data including time series of catch and survey catch rates

## The dish: Le stock assessment du Réverend

Bayesian fisheries stock assessment is effective at conveying uncertainty about stock status and at evaluating management options, but the most widely used algorithm, Markov Chain Monte Carlo (MCMC), is slow and can fail to converge. While convergence is tested by various diagnostics, these can only reveal failure, never success. Therefore, this paper suggests using Bayesian network propagation (BNP) to compute posterior results instead. Converting the continuous assessment model to a Bayesian network (BN) using Fuzzy Discretization makes this possible.

## Directions

1. Draw the graphical representation of the assessment model, as in Figure 1
2. Convert continuous model equations and distributions to conditional probability tables (CPTs), using Fuzzy Discretization (see below)
3. Construct a BN from the results of 1 and 2
4. Introduce survey catch rates (or other data) as 'evidence' on the BN
5. Propagate the evidence with BNP
6. Refine the discretization of continuous variables and repeat 2-5, until the state grids of each variable align with the interval of high marginal posterior probability
7. Use the final BN to estimate quantities of interest, like the carrying capacity ( $K$ )

### Preparation Technique: Fuzzy Discretization

Fuzzy Discretization converts continuous equations and distributions into CPTs. While converting distributions is relatively straightforward, equations are trickier. For example, let random variables  $X$  and  $Y$  have states  $\{0, 1, 2, 3\}$  and let r.v.  $Z$  have states  $\{0, 2, 5\}$ . The object is to obtain a conditional probability table for  $Z$ , namely  $P(Z|X, Y)$ , from the equation  $Z = (X + Y)$ .

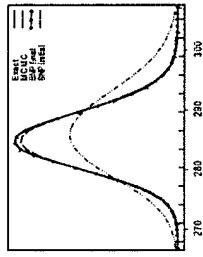
When  $X = 1$  and  $Y = 1$ ,  $Z$  should be in state 2, since  $1 + 1 = 2$ , so Fuzzy Discretization would assign probability one to  $Z$  being in state 2 and probability zero to states 0 and 5. Similarly, when  $X = 0, Y = 0$ ,  $Z$  should then be in state 0 with probability one.

For other cases, the 'Fuzzy Result Rule' applies. When  $X = 1$  and  $Y = 2$ , for example, their sum is not a  $Z$  state. The two closest  $Z$  states are 2 and 5 and 3 is twice as far from 5 as it is from 2. Following this rule, Fuzzy Discretization would assign twice the probability to 2 that it assigns to 5 and other states get nothing. When the exact answer falls between two states, the Fuzzy Result Rule partitions all the probability between them and the share assigned to each state is inversely proportional to the distance to the exact answer. If the exact answer falls outside the state grid, as it does when  $X = 3$  and  $Y = 3$ , all probability is assigned to the closest state, which would be 5. In general, compute the exact equation result, compare it to the states of the result r.v. and apply the 'Fuzzy Result Rule', as necessary.

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T.R. Hammond, DRDC – Atlantic, 9 Grove Rd., Dartmouth, NS, Canada.  
Tim.Hammond@drdc-rddc.gc.ca



## Figure 1

This is a Bayesian network, in which random variables are represented with labeled bubbles. Complete specification of this Bayesian network requires defining conditional probability table for each variable. For a particular variable must be defined given the states of any other variables that point to it with arrows. For example, the label for  $B1|B1$  would be conditional on  $P1|S0, C1|S0$ , and  $K$ .

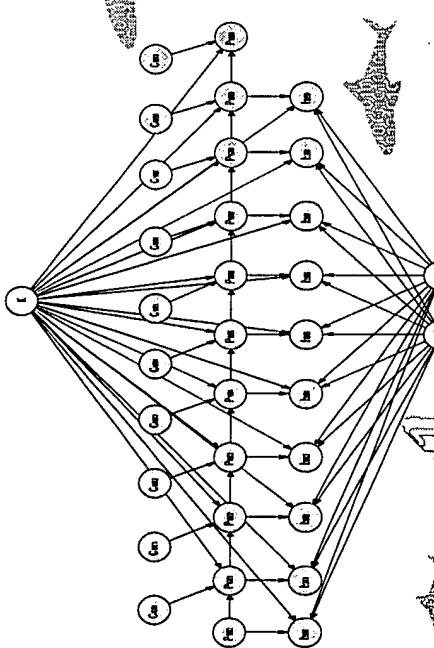


Figure 2: This is a map of Canada, in which random variables are represented with labeled bubbles. Complete specification of this Bayesian network requires defining conditional probability table for each variable. For a particular variable must be defined given the states of any other variables that point to it with arrows. For example, the label for  $B1|B1$  would be conditional on  $P1|S0, C1|S0$ , and  $K$ .

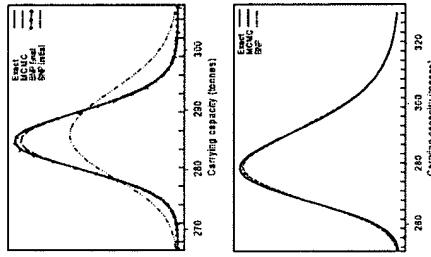


Figure 3: The marginal posterior density estimates for  $K$  from BNP and MCMC are compared to the exact answer assuming  $q$  and  $t_2$  are known. The exact and BNP estimates are virtually indistinguishable by eye. The grid of states is shown with a rug of tick marks along the horizontal axis. The initial BNP density estimate obtained before all groups the state grids with regions of high posterior probability is also shown. Illustrating the dramatic performance improvement this entails.

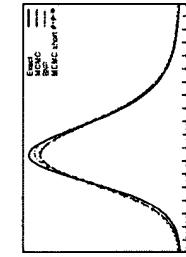


Figure 4: The marginal posterior density estimates for  $K$  from BNP and MCMC are compared to the exact answer when parameters  $K$ ,  $a$  and  $t_2$  were all estimated. BNP outperforms MCMC once again. The MCMC short run results were obtained with only 250 000 iterations (as opposed to 500 000). These short run results are virtually indistinguishable from the long-run ones.

## Performance

The technique was applied to the Schaefer assessment model of Meyer and Millar (1999), illustrated in Figure 1. Posterior density estimates for carrying capacity ( $K$ ) from both MCMC (as implemented in WinBUGS (<http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml>)) and BNP (as implemented in WinBUGS (<http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml>)) were compared to exact results (obtained by analytic integration and grid-search) under three scenarios (Figures 2, 3 and 4). BNP outperformed MCMC in all scenarios, though the single-chain MCMC diagnostics in the BOA toolkit (<http://www.public-health.uwyo.edu/boa/>) reported no problems.

While WinBUGS took over three hours to compute results in each figure, BNP took 3 seconds, 3 minutes, and 67 minutes to compute results in Figures 2, 3 and 4, respectively. BNP used a minimum of 25 states to discretize each continuous variable, and BNP run time is very sensitive to this number.

## Conclusion

In summary, this recipe may provide a fast alternative to MCMC for similar Bayesian problems.

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Pages:421 - 428

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[25](#) [26](#) [27](#) [28](#) [29](#) [30](#) [31](#) [32](#) [33](#) [34](#) [Next](#)

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